Section 6. SOME GUIDES FOR THE PILE DRIVING FOREMAN AND INSPECTOR

1. INTRODUCTION. This section deals with important considerations that are under the control of field personnel when installing piling with an impact hammer, to achieve a desired capacity to resist downward axial loads. There are many considerations that are controlled by the designer, such as the type and size of pile, penetration requirements, pile spacing, and tolerances on location, all of which are prescribed before the work begins. These are not considered here. There also are cases where the capacity of piling to resist uplift or lateral loads is important. These cases, too, are not considered here.

In general terms, a pile driving operation must be evaluated in terms of overall performance, i.e., how much of the blow of the hammer is transferred into usable work in moving the tip of the pile. To this end, paragraphs 3 to 8 must be considered.

Also, the loss of energy into those ground strata that are not expected to contribute to the support of the pile (generally, the strata above the bearing stratum) should not be included in evaluation of the penetration resistance achieved. To this end, paragraphs 9 to 15 must be considered.

2. SOME PRELIMINARY MATTERS.

a. Job Specifications. Specifications must be read and understood. Are piles to be driven to resistance only, or is a specified bearing stratum to be reached? Is a minimum penetration (tip elevation or penetration into bearing stratum) required? What alternatives are permitted? What is the intended function of the piles (resistance to downward load; resistance to lateral load, resistance to uplift, compaction of soil, etc.)? Job specifications should present this information.

b. Preparation of Site. Coordinate with the excavator who should be persuaded (or compelled) to prepare the site for efficient movement of the pile rig, for access and egress, for delivery of materials, and for their storage. Has dewatering been provided? Will the braces for the excavation be in the way? If so, what provision has been made for their removal?

c. Coordination With Other Trades. Pile installation is dependent on preparatory work by the excavator. Similarly, the concrete work and other trades are dependent on completion of installation of piling and must be coordinated with full consideration of the needs of all parties. Proper scheduling of delivery of materials and equipment is essential to ensure continuity of operations, once the work is started.

3. CONDITION OF HAMMER AND POWER EQUIPMENT.

It will be apparent that the driving equipment must be in good condition if the hammer blow is to be properly delivered to the pile. For example, the hoses must not be kinked or crimped, valves should be fully opened, the hammer must not bind in the leads, and the cap should bear fully on the head of the pile, which should be trimmed to fit.

To check the output of the hammer, the following items may be observed:

a. Steam or Air Hammer. The gauges at the power source are the basic check. Determine that there are no leakages between the power source and the ram, that line sizes are ample to preclude excessive losses, and that line lengths are not excessive. These factors are reflected in the proper ram rise which should be checked. The instance of getting so much ram rise that the ram strikes the top yoke should be avoided, not only because of possible damage to the hammer, but because there is a tendency to lift the hammer off the pile.

b. Diesel Hammer.

(1) Check the fuel. A fuel with a lower BTU content will decrease the energy output. Check the fuel used against the manufacturer's recommendations.

(2) Check the fuel input by checking the pump setting against the manufacturer's standard.

(3) Unsteady hammer operation should be a signal to check the fuel pump and related components and to check for vapor lock.

(4) Observe the exhaust for indications of water in the fuel.

(5) Check the compression ratio. In the open-top diesel, the time required for the piston to stop bouncing on the cylinder's air cushion is an indicator. In the closed-top diesel, check the gauge on the upper chamber bounce.

4. SPEED OF HAMMER. For impact hammers, all other things being equal, the energy delivered is a function of the speed of the hammer. In general the faster the succession of blows the more energy delivered to the pile, and hence the greater the capacity for a given indicated set. The hammer speed must be checked during driving by a timed count of blows. The manufacturer's rated speed should be adhered to.

5. CUSHION OR CAP BLOCK. The hammer blow usually is delivered to the pile through a cushion or cap block. This block absorbs part of the energy of the impact and reduces that part which is delivered to the pile.

The cap block must be kept in good condition, although readings of penetration resistance should not be made immediately after a new block or cushion is installed or until the new material has had an opportunity to be properly set. It must be of reasonably firm materials and must be replaced when crushed. As a rule of thumb, some practitioners inspect the cushion material every 1000 blows, replacing it if excessively compressed or excessively disrupted. Unless these things are tended to, the recorded sets will be too low, often drastically so. Special care should be taken that foreign energy-absorbent materials (wood chips, pieces of rubber, etc.) are not used in the cap-block recess.

6. FOLLOWERS. When a follower is used, the apparent sets will be too low. There are two reasons: (1) the effective weight of the pile is increased and

(2) if the follower does not fit tight, there is an energy loss due to "chatter" and to separation between pile and follower under the impact wave.

The effect of the weight of the follower can be considered by use of the Hiley (or similar formulas). The remedy for relative movement or chatter is to provide the follower in a single-length section, stiff enough to prevent whip during driving and to insist that the follower fit tightly to the pile.

Followers should be of steel, hardwood, or similar material which will minimize absorption and cushioning of the hammer blow in the follower.

7. DISTORTION OF THE PILE AXIS. Distortion of the pile axis (Figure 17) commonly is observed. It is caused by the presence of obstructions in the soil, variations in soil density, eccentric blow of the hammer, skewing the leads, or other factors that tend to cause the pile to walk off-line. Distortion of the pile axis is detrimental to the capacity of the pile because:

(1) bending stresses are introduced into the pile;

(2) the effectiveness of the hammer blow is reduced because energy is used up in "whip" of the pile.

Care should be taken to minimize the occurrence of distortion of the pile axis as, for example, not using excessive force to hold the pile head in position. Frequently, as the pile is being driven, it will tend to drift off location and/or plumb or batter. When only a short length of pile is in the ground it is usual to guide the pile back into desired alignment by raising or lowering the boom, by travelling against the pile, or by use of the spotter. Once substantial penetration has been made, however, such attempts are likely to be more illusory than effective and the detriments in terms of broken piles and/or locked-in stresses exceed the benefits. When this occurs, consideration should be given to "following" the pile down, i.e., to allow it to seek its own course into the ground. There is substantive evidence that, within broad limits, the fact of the embedded portion of a pile being out-of-plumb has little effect on its strength or capacity.

In cast-in-place, pipe, or caisson piles, the deviation of the pile axis from a straight line should be checked against the specified tolerance (usually that a portion of the tip of the pile can be seen). If distortion is suspected, the penetration resistance should be increased, say, 10% to 20% to compensate the loss of hammer blow energy due to "whip" of the pile.

8. DAMAGE DURING DRIVING. Some examples of damage to piling due to driving are shown on Figures 18 and 19. Prevention consists in not overdriving the pile. This may, however, be at variance with the requirements for minimum penetration or for the development of a specified penetration resistance. Accordingly, the problems of damage to piling during driving often becomes a matter of determining how hard one can drive the pile without damage. This, in turn, becomes a problem of detecting damage when it does occur. Indicators of possible damage to a pile during driving include:

(1) A sudden decrease in penetration resistance indicating breakage of the pile.

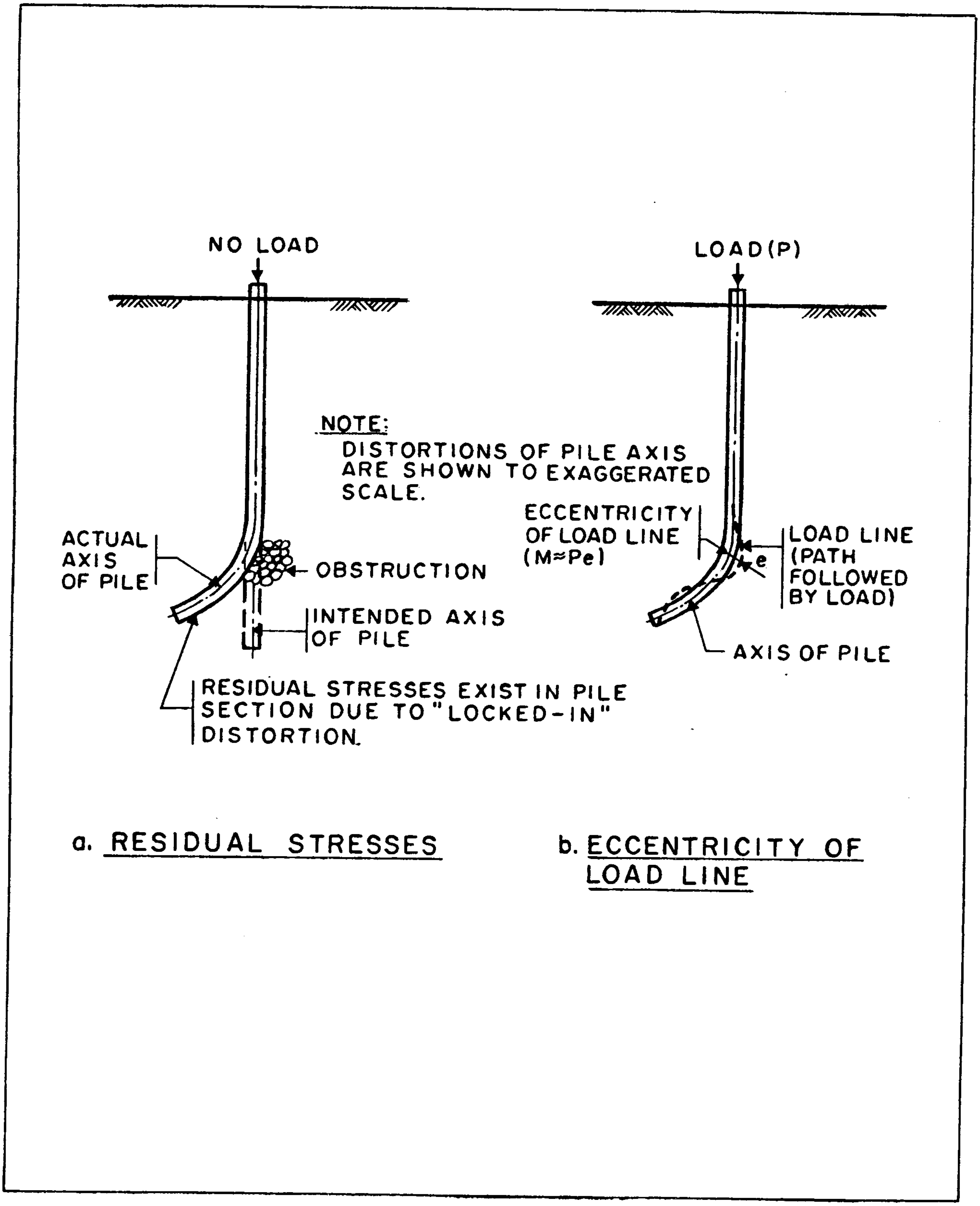
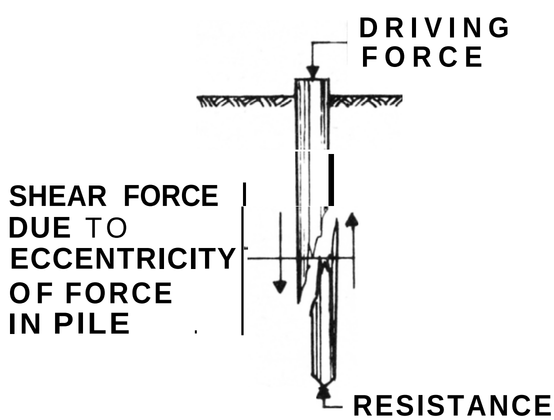


FIGURE 17
Effects of Distortion of Pile Caps

a. CRUSHING OF TIPS OF TIMBER PILES DUE TO OVERDRIVING

b. DAMAGE TO BUTT OF TIMBER PILE DUE TO HARD DRIVING



c. DIAGRAMMATIC REPRESENTATION OF BROKEN TIMBER PILE

FIGURE 18
Damage to Piling Due to Driving

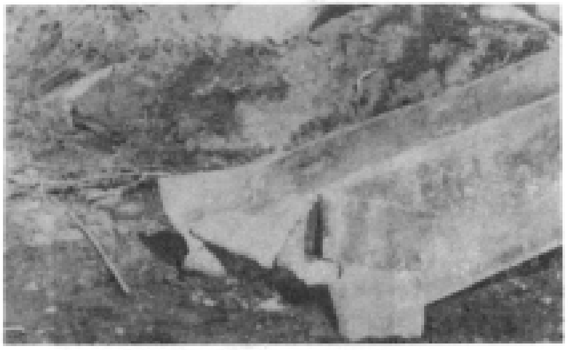


FIGURE 19
Damage to Steel "H" Piles Due to Overdriving

(2) Sudden, lateral "snap" of the head of the pile, indicating breakage due to bending.

(3) Damage to the head of the pile, possibly reflecting similar damage to the tip.

(4) Two, or more, cycles of alternating decrease and increase in penetration resistance, indicating progressive crushing of the tip.

(5) Periodic vibration of piles previously driven, indicative of interference with pile currently being driven.

(6) Crushing or distortion of the pile as indicated by internal inspection of cast-in-place pipe, or caisson piles prior to concreting.

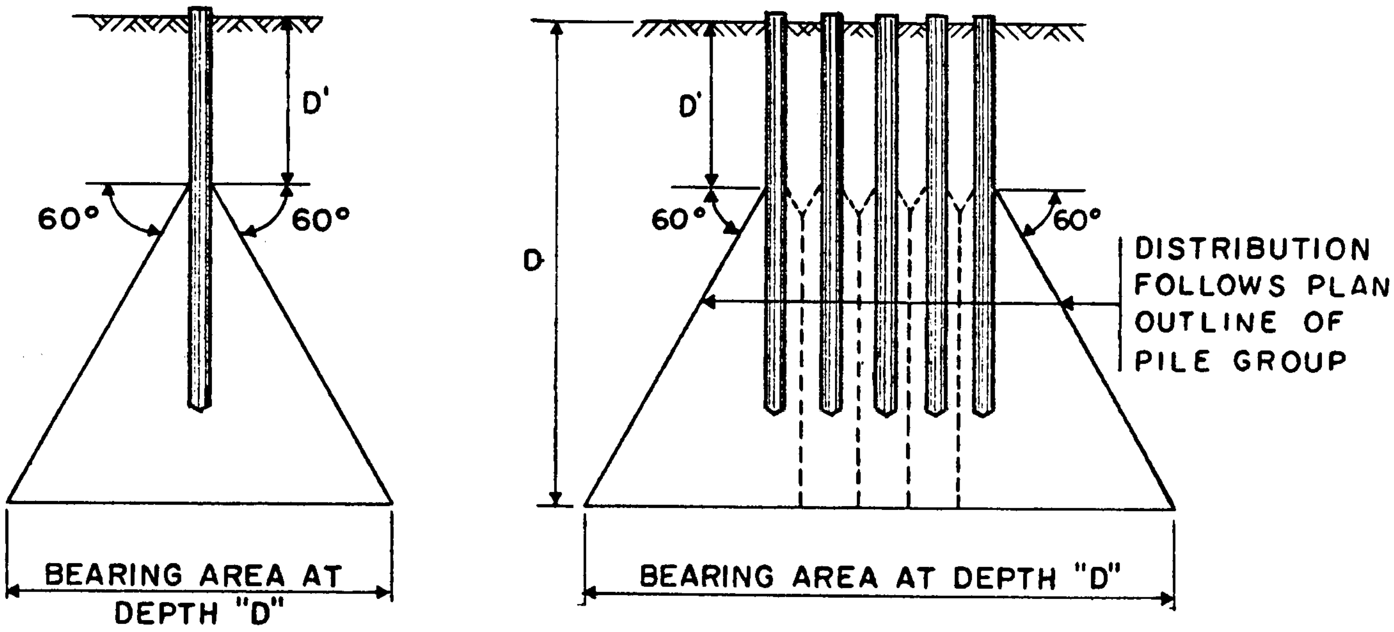
(7) Driving resistance suddenly increases or becomes irregular, whereas the soil formation cannot account for it, indicating breakage.

(8) The pile suddenly begins to move, laterally.

Care also must be observed in filling cast-in-place concrete or pipe piles to assure that there are no voids. To this end a 6-inch, or greater, slump normally is used.

9. SUSTAINED DRIVING RESISTANCE. For piles installed by impact hammer, the capacity normally is measured by the resistance to penetration, expressed in terms of the number of blows per foot of penetration or per inch of penetration. It is common to assume that the two measures (per foot or per inch) have the same significance. For example, it is commonly assumed that a pile has the same capacity whether driven to 60 blows per foot, or 5 blows per inch, or 1 blow per 1/5 inch and such a pile often will be stopped, in order to reduce the chances of damaging the pile, as soon as the resistance mounts to 5 blows for a one-inch distance. However, this assumption is not correct. In practice, the pile driven to 60 blows per foot usually will perform better, i.e., it will settle less under the same applied load, than the one driven to 5 blows per inch. The reason is that pile capacity largely is a function of the amount of energy expended on installing the pile and not just of the final resistance. Therefore, within the limitation that the pile not be driven so hard that it is damaged, a sustained driving resistance for, say, one foot, is advisable.

10. EXCESSIVE VARIATION IN PILE LENGTH. It is often observed that the lengths of the piles in a footing are not all the same. This is due to several factors. The soil is not uniform. The soil is progressively compacted as successive piles are installed. The level of the bearing stratum varies. Where large (more than, say, 5 to 10 feet) variations in length occur, the adequacy of the group should be questioned. If feasible, the matter should be brought to the attention of the designer. If not feasible, the matter may be judged, in a rough way, by reference to the Equivalent Footing Analogy. (See Figure 20.)



(a) FOR SINGLE PILE

(b) FOR PILE GROUP

NOTES: 1) BEARING AREA DOES NOT EXTEND BEYOND THE INTERSECTION OF THE 60° PLANES

2) D'=DEPTH TO LEVEL OF EFFECTIVE LOAD TRANSFER INTO SOIL

a. FOR PILES EMBEDDED IN GRANULAR OR FIRM (OR STIFF) COHESIVE SOILS

FIGURE 20 (1 of 2)
The Equivalent Footing Analogy

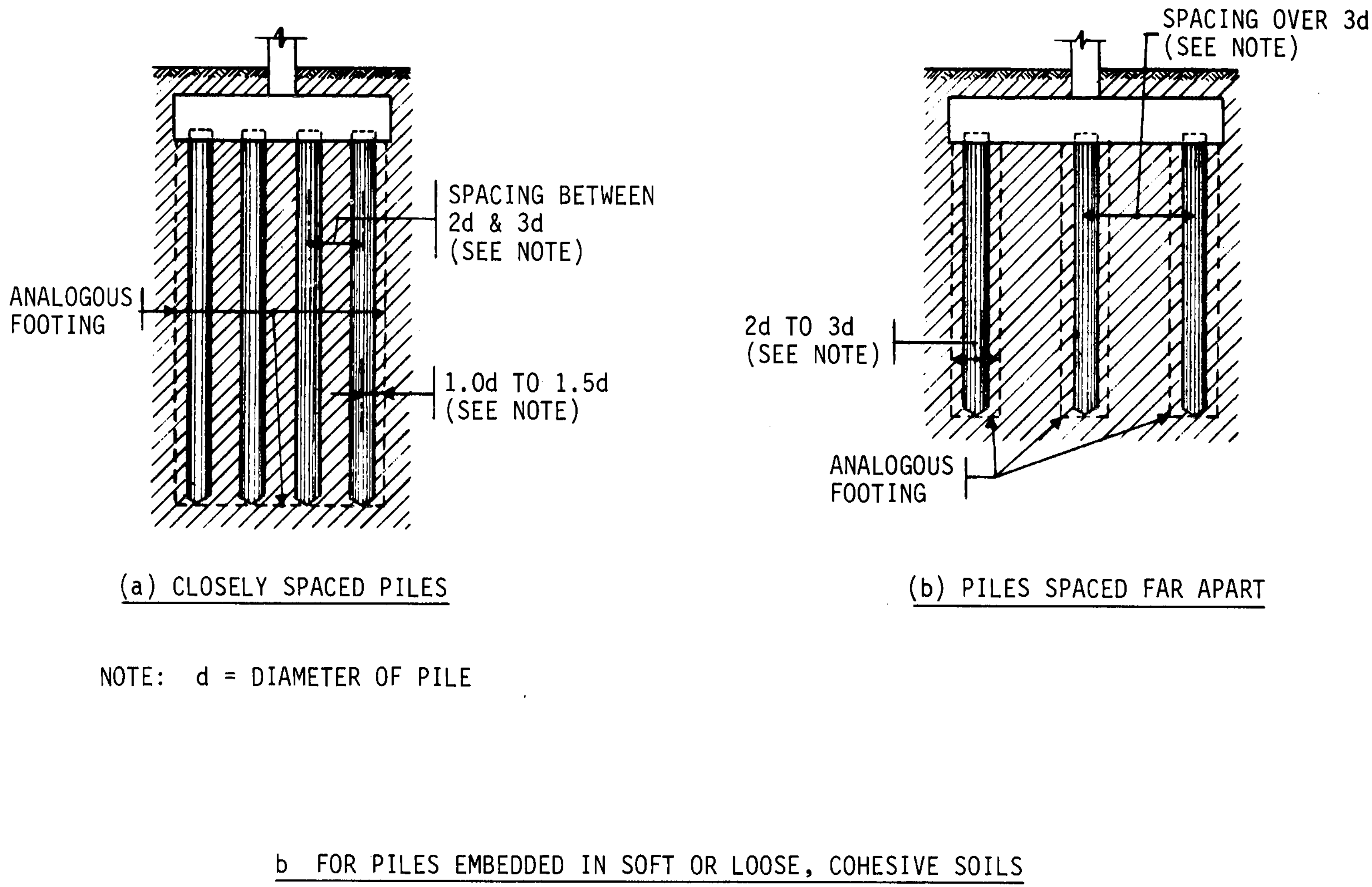


FIGURE 20 (2 of 2)
The Equivalent Footing Analogy

11. MINIMUM ENERGY OF HAMMER. It will be apparent that it makes no sense to try to drive a spike with a tack hammer. The same thing applies to driving piles. Unless the hammer is heavy enough, a pile can have a very low apparent set but without attaining any significant penetration or capacity. This is the reason for the provisions relating to minimum energy in Tables 1 and 2.

12. WHERE DRIVING IS INTERRUPTED. For piles in cohesive (or mixed) soils, if driving is interrupted, there is a tendency for the pile to set-up or freeze; i.e., upon the resumption of driving the set will be much less than that recorded before the interruption. Under such circumstances, the assumed correlation between capacity and penetration resistance is not meaningful, and the pile must be driven a sufficient distance to break the freeze, before readings of penetration resistance can be interpreted. The distance may be a few inches or several feet. A value of 5 feet commonly is used.

13. JETTING. The use of jetting sometimes is required in order to obtain sufficient penetration to get the piles to bear in satisfactory material below compressible strata that may underly the site.

The jetting operation disturbs the soil around and below the pile (this being its function), and readings of penetration resistance should not be taken while jetting is in progress or until the pile has been reseated after jetting has been completed.

14. SEQUENCE OF INSTALLATION AND TOO-CLOSE SPACING. As the piles for a group are driven, the surrounding and underlying soil is compacted, both by the volumetric displacement of the piles and by the vibrations incident to driving. As a result, the ground tightens up, and the last piles driven tend to run shorter, for a given penetration resistance requirement, than the first piles installed. This is particularly true when the piles are "boxed in" by driving; i.e., the perimeter piles in the group are driven first and the center piles then are filled in, or when the pile spacing is too small so that succeeding piles must be driven through progressively more compact soil. These procedures should be avoided. Excessive variations in length should be investigated, as described in paragraph 10.

15. HEAVED PILES. Another possible detrimental consequence of improper sequence of installation and/or too-close spacing of piles is that the piles installed first in the sequence may be heaved by the ground displacements resulting from installation of the subsequent piling. In addition, the lateral pressures developed in the soil may displace (or break) adjacent piles or damage nearby buildings or utilities.

Most engineers consider that heave is detrimental to pile capacity and that the heaved piles will settle under load by an amount approximately equal to the original heave plus the normal settlement otherwise anticipated. Accordingly, it is concluded that heaved piles must be redriven to bearing, although a nominal amount of heave (say, 1/4 inch) generally is considered to be acceptable without bothering to redrive.

Heave is not necessarily detrimental, however, depending on circumstances. Cases of heave should be referred to the design engineer for evaluation.